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# **Fuzzy Control Course**

## **Lec 4**

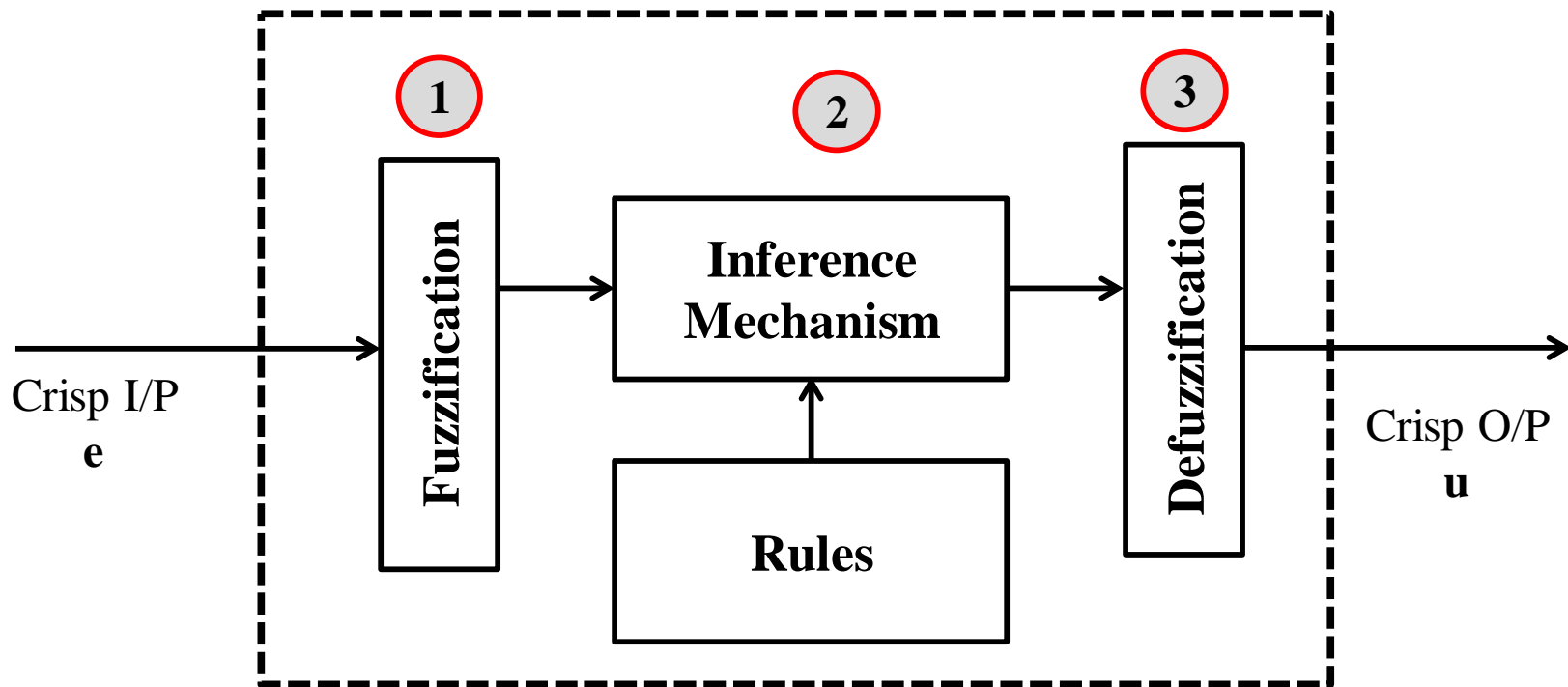
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# **Structure of Fuzzy Controllers**

## **(Examples of Fuzzy Rules)**

*DR. M. Arafa*

# Fuzzy Controller Structure



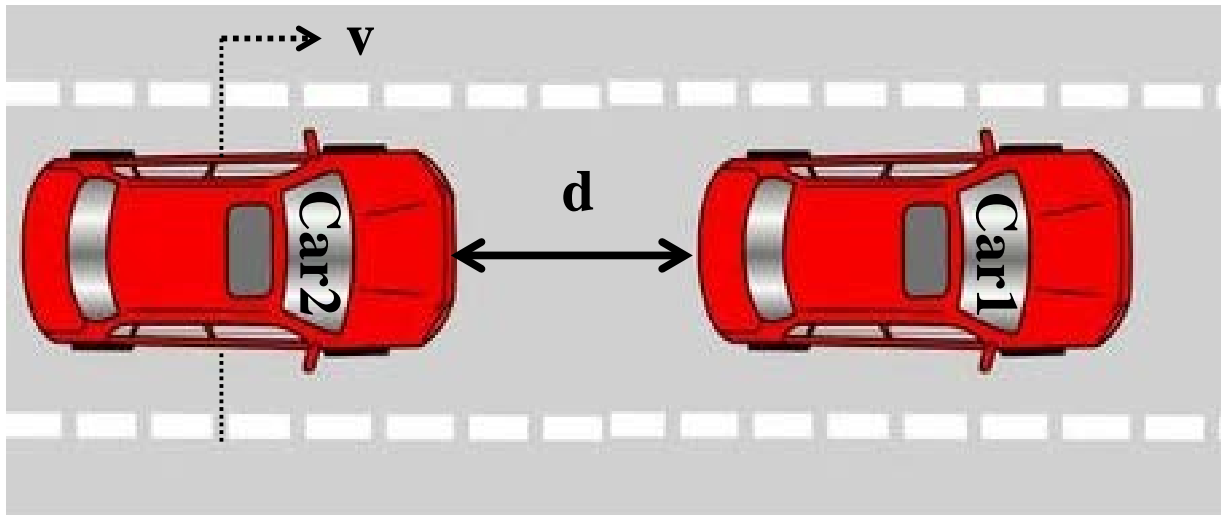
## Fuzzy Controller

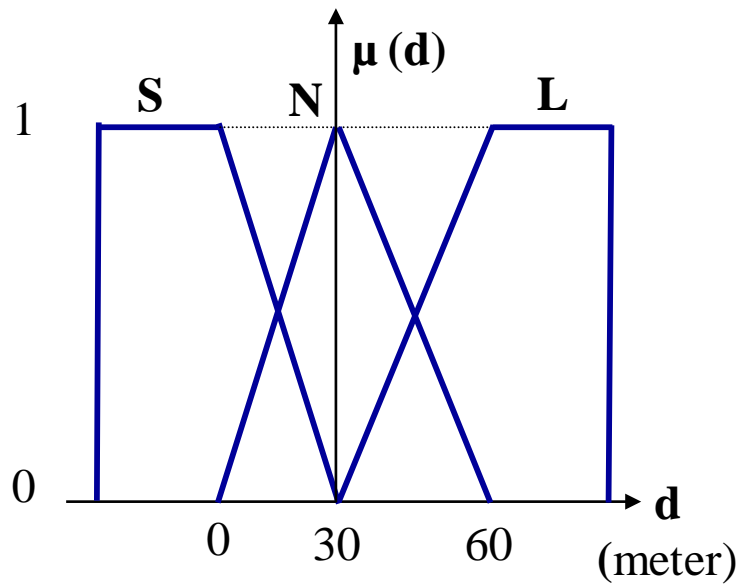
- Crisp means numeric (or real) value

## Quiz: Braking Control of A Car

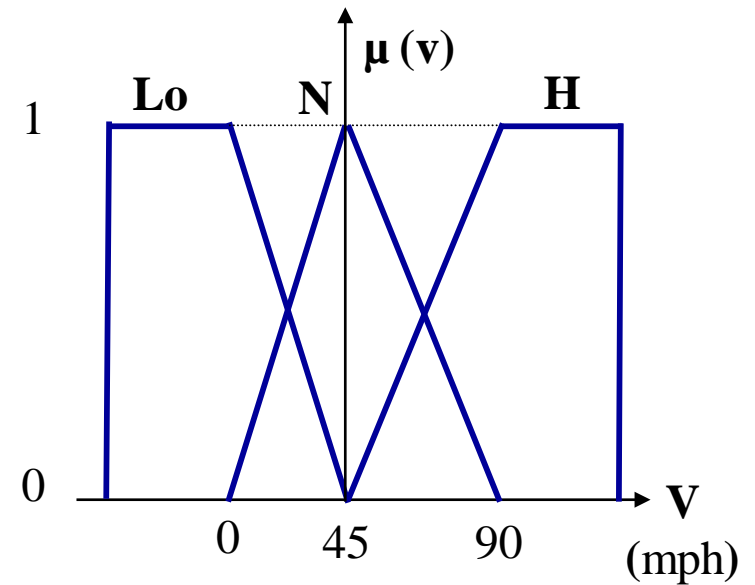
- Consider two cars (car1 and car2) separated by distance (d) which takes range from 0 to 60 meter.
- Car2 moves at speed (v), which takes range from 0 to 90 m/h.
- Depending on the speed (v) and distance (d), car2 has several braking options which take range from 0 to 100.
- Write suitable rules to design a fuzzy logic controller for car2 to control its braking options.
- Consider the inputs and output of the controller have three fuzzy sets: {S, N, L} for the input **d**, {Lo, N, H} for the input **v** and {Lo, M, H} for the output **u**.  
where: **S**= short , **N** = normal , **L** = long , **Lo** = low , **M**= medium, **H**= high
- These fuzzy sets are shown in the following figures.

## Quiz: Braking Control of A Car

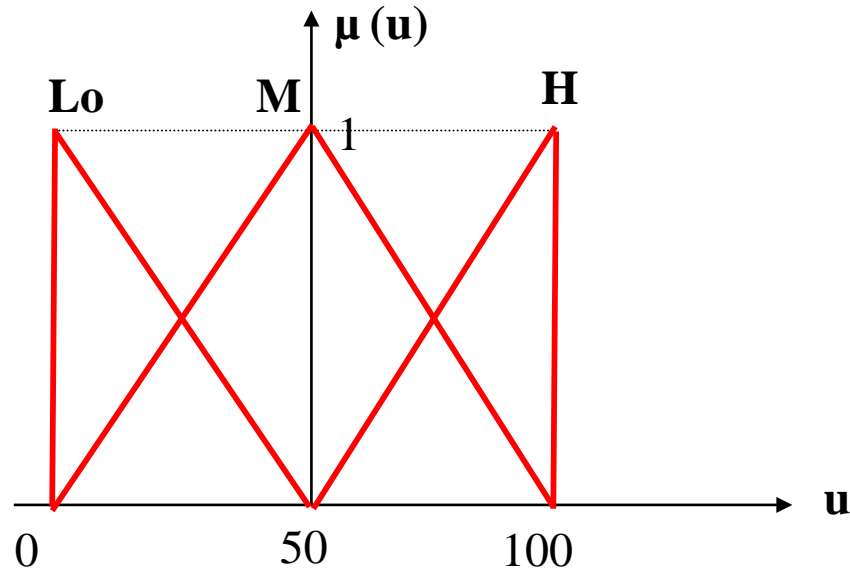




Membership Functions (MFs) of input  $d$



Membership Functions (MFs) of input  $v$



Membership Functions (MFs) of output  $u$

**S** = “short”

**N** = “normal”

**L** = “long”

**Lo** = “low”

**M** = “medium”

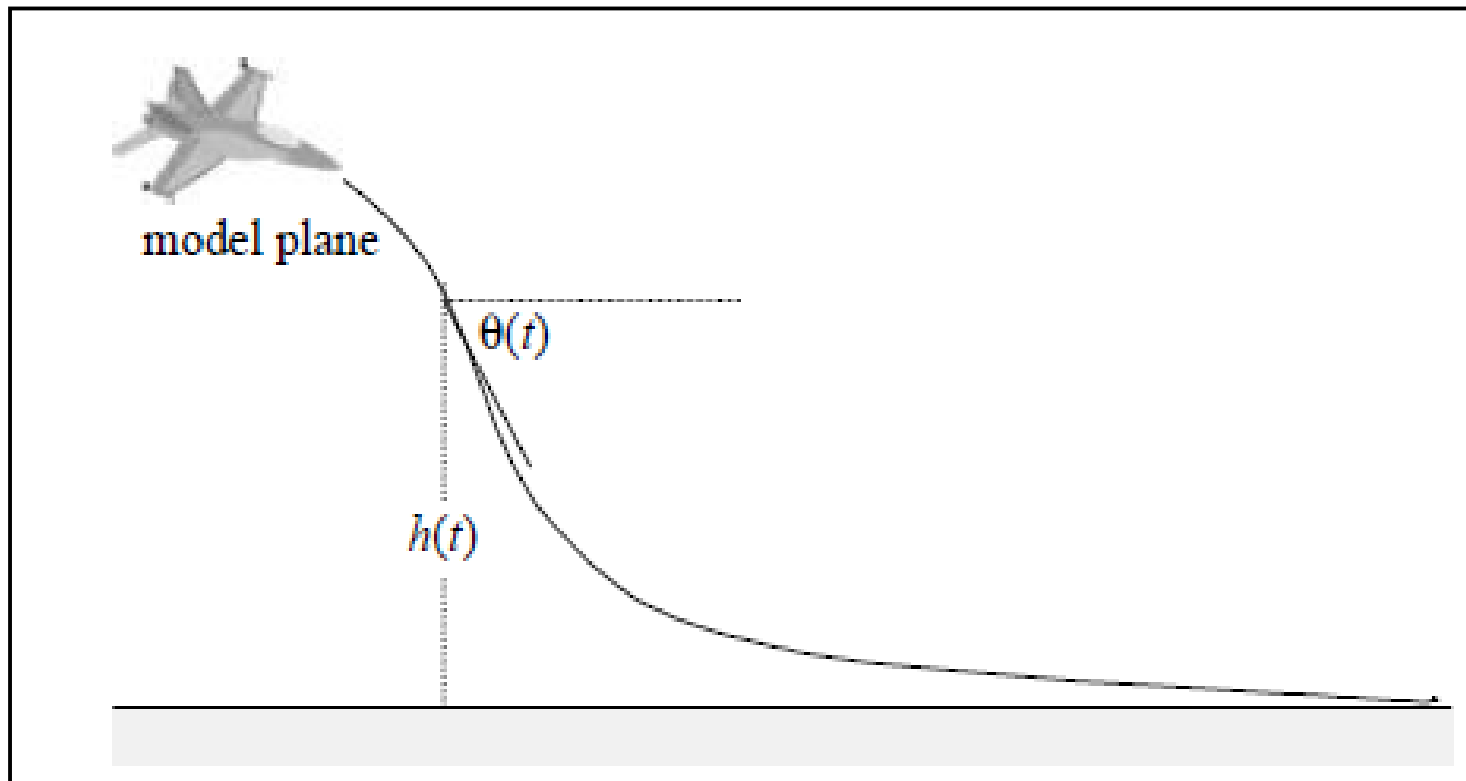
**H** = “high”

➤ The Table of Rules:

<div> <div>d</div> <div>v</div> </div>	S (short)	N (normal)	L (long)
Lo (low)	M	Lo	Lo
N (normal)	H	Lo / M	Lo
H (high)	H	M / H	M

## Ex1: Airplane Landing Control Problem

- Consider a landing control problem of air plane model, as shown in the following figure:





## **Ex1: Airplane Landing Control Problem**

- Write suitable rules to design a fuzzy logic controller to land the plane safely, anywhere on the ground (the x-axis).
- Since the plane can land anywhere on the ground, we do not specify the parameter for the horizontal axis.
- Assume that no mathematical model for the plane is available for the design, but the plane is equipped with sensors that can measure the height  $h(t)$  and the angle  $\theta(t)$  of motion of the plane.
- Suppose that the model plane is moving forward at a constant speed and the controller is used to steer the angle of the plane.
- The fuzzy logic controller provides the control action  $u$  which controls the angle of the plane, so as to guide it to land on the ground safely.

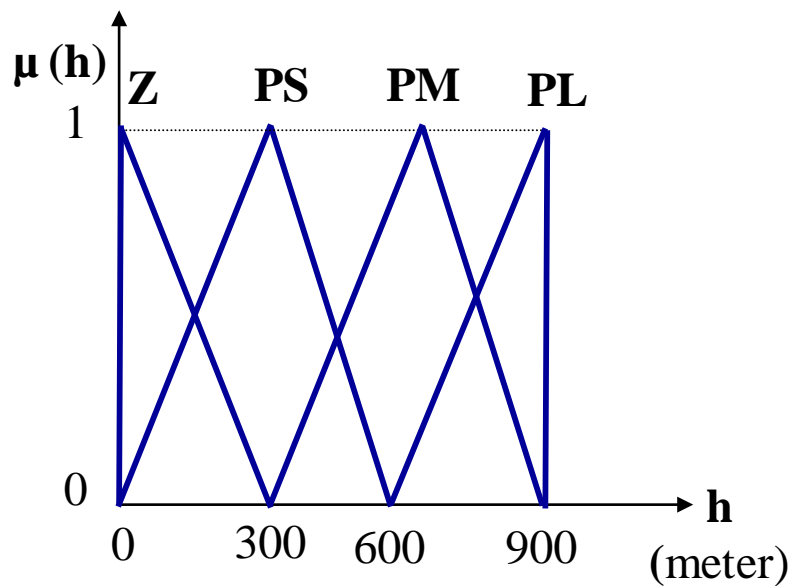
- The inputs of the fuzzy controller are the angle  $\theta(t)$  of motion of the plane and the height (vertical position coordinate)  $h(t)$  of the plane while the output of the fuzzy controller is the steering angle  $u$ .



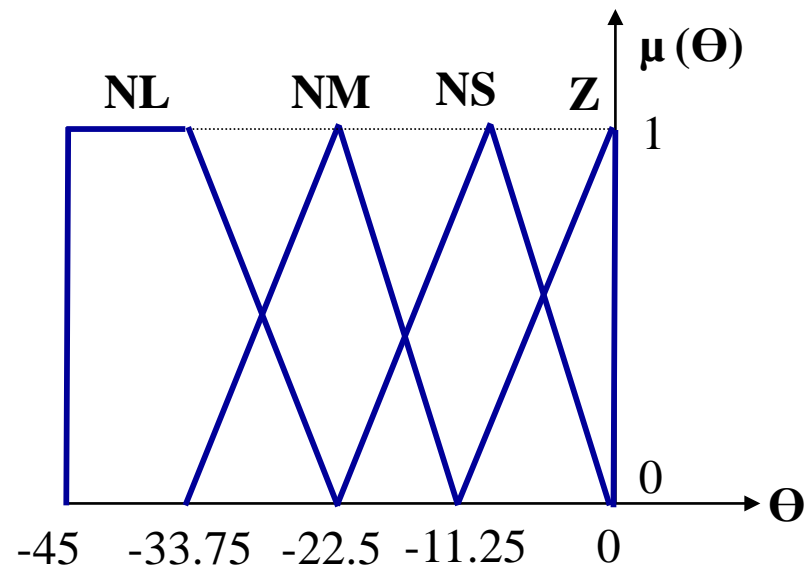
- Consider the inputs of the controller have four fuzzy sets:  $\{Z, PS, PM, PL\}$  for the input  $h$  and  $\{NL, NM, NS, Z\}$  for the input  $\theta$ . The output of the fuzzy controller  $u$  has seven fuzzy sets:  $\{NL, NM, NS, Z, PS, PM, PL\}$ . These fuzzy sets are shown in the following figures.

where:

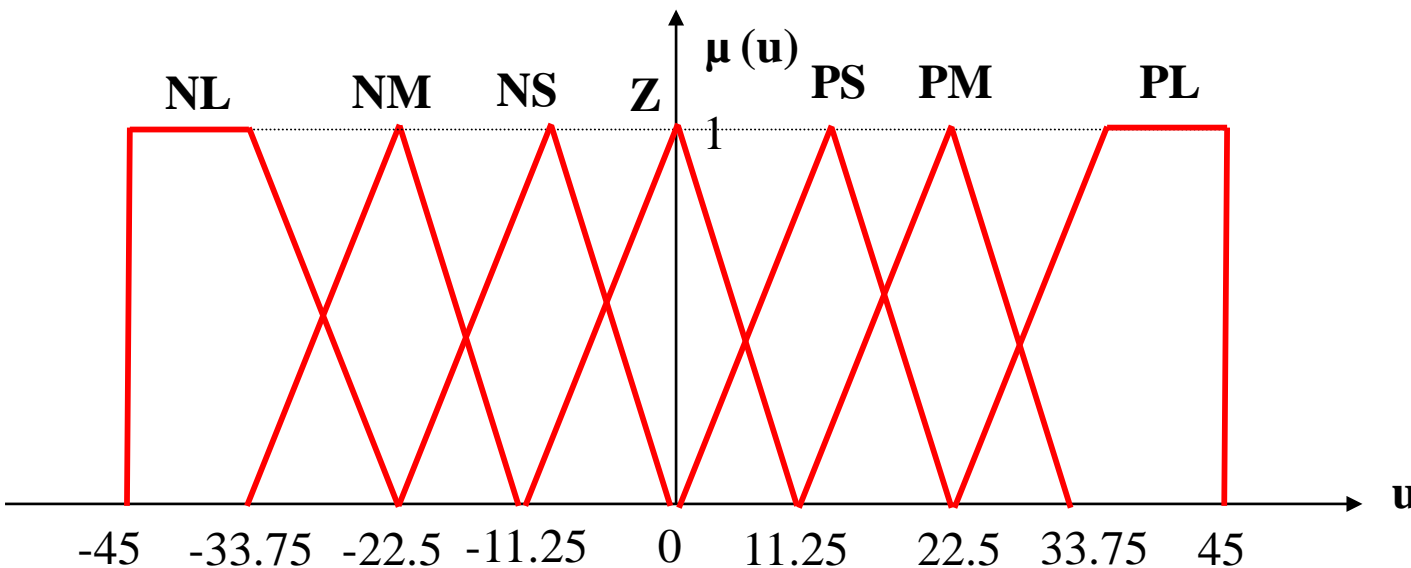
**NL** = “Negative\_large”, **NM** = “Negative\_medium”, **NS** = “Negative\_small”, **Z** = “Zero”  
**PS** = “Positive\_small”, **PM** = “Positive\_medium”, **PL** = “Positive\_large”



Membership Functions (MFs) of input  $h$



Membership Functions (MFs) of input  $\Theta$



Membership Functions (MFs) of output  $u$

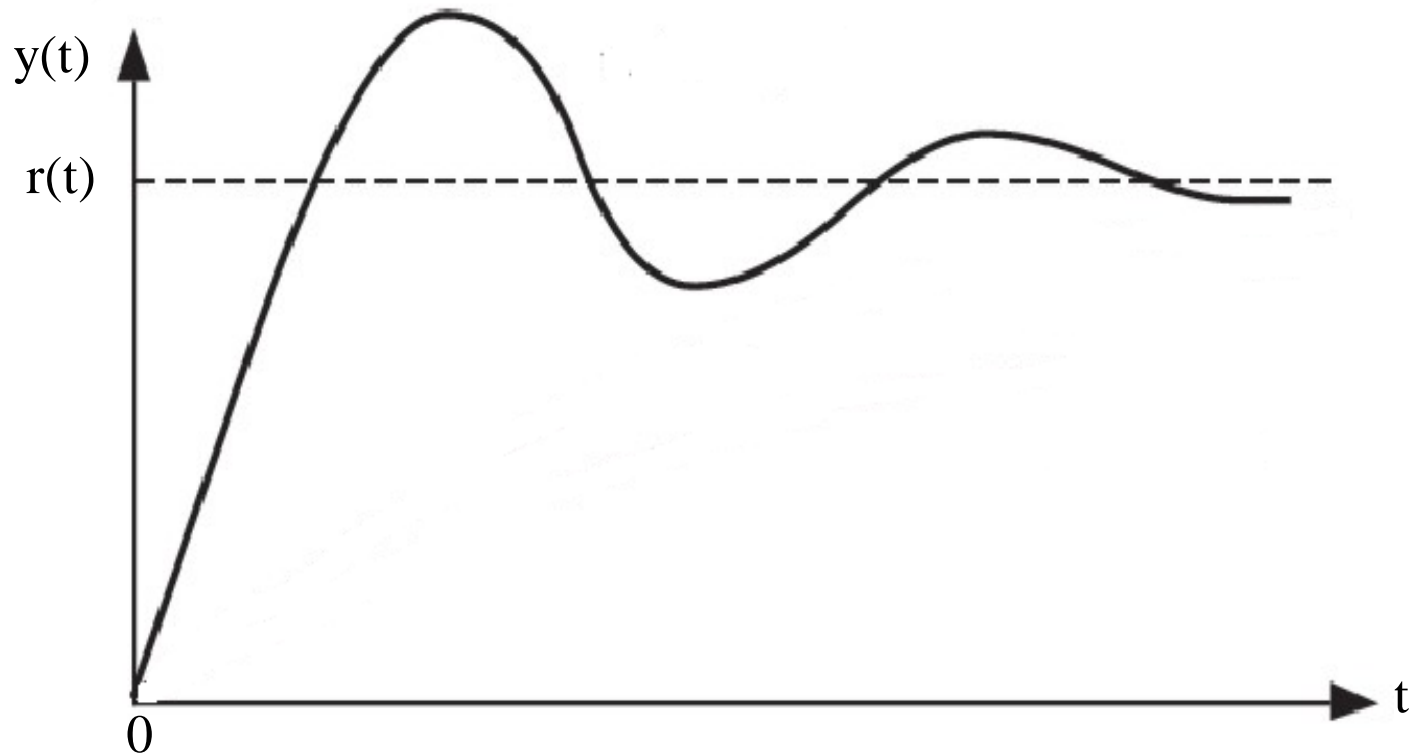
**NL** = "Negative\_large"  
**NM** = "Negative\_medium"  
**NS** = "Negative\_small"  
**Z** = "Zero"  
**PS** = "Positive\_small"  
**PM** = "Positive\_medium"  
**PL** = "Positive\_large"

➤ The Table of Rules:

$\begin{array}{c} \theta \\ h \end{array}$	NL	NM	NS	Z
Z	PL	PM	PS	Z
PS	PM	PS	Z	NS
PM	PS	Z	NS	NM
PL	Z	NS	NM	NL

## Ex2:

- Write a suitable rules to design a fuzzy-PD controller to minimize the overshoot of the step response for following system :



- The inputs of the fuzzy controller are the error ( $e$ ) & change of error ( $\Delta e$ ) and the output is  $u$ .



Where:  $e(t) = r(t) - y(t)$

$$\Delta e(t) = e(t) - e(t - t_0)$$

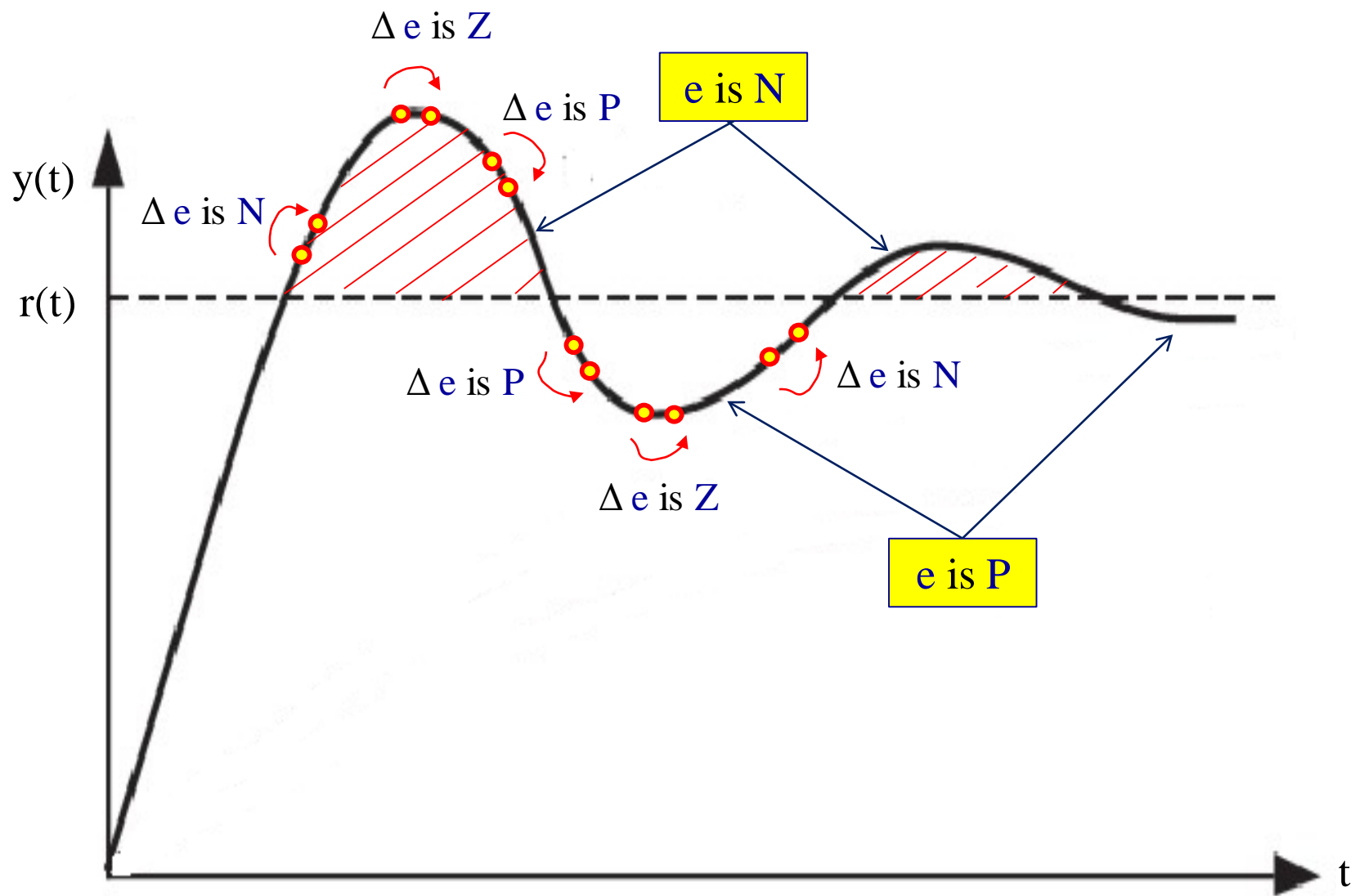
- Consider the inputs and output of the fuzzy controller have three fuzzy sets:  $\{N, Z, P\}$ .

where:

**N** = “Negative”

**Z** = “Zero”

**P** = “Positive”



➤ The Table of Rules:

$\Delta e$ \ e	N	Z	P
N	P	P	Z
Z	P	Z	N
P	Z	N	N



### Ex3:

- Rewrite the rules for the fuzzy controller of the pervious example, if we change the no. of fuzzy sets for inputs and output of the controller to seven, these fuzzy sets are: { NL, NM, NS, Z, PS, PM, PL }

where:

**NL** = “Negative\_large”

**NM** = “Negative\_medium”

**NS** = “Negative\_small”

**Z** = “Zero”

**PS** = “Positive\_small”

**PM** = “Positive\_medium”

**PL** = “Positive\_large”



➤ The Table of Rules:

$\Delta e$ \ e	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	PM	PS	Z
NM	PL	PL	PL	PM	PS	Z	NS
NS	PL	PL	PM	PS	Z	NS	NM
Z	PL	PM	PS	Z	NS	NM	NL
PS	PM	PS	Z	NS	NM	NL	NL
PM	PS	Z	NS	NM	NL	NL	NL
PL	Z	NS	NM	NL	NL	NL	NL

## Fuzzy-PID Controller

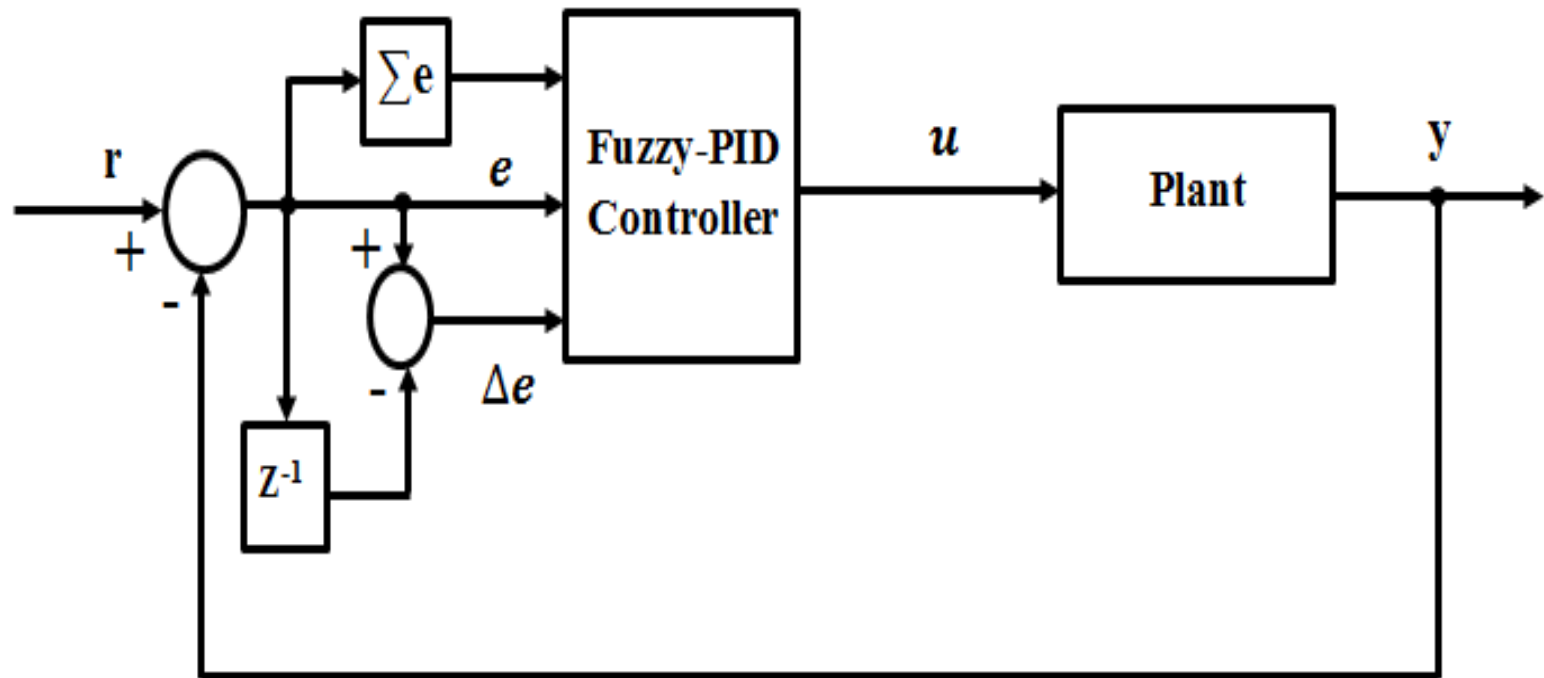
- A PID controller is used to obtain a better performance in respect of rise time, settling time, overshoot and steady-state error.
- The basic idea of a PID controller is to choose the control law by considering the error  $e$ , change of error  $\Delta e$  and integral of error  $\int_0^t e \cdot dt$  :

$$u_{PID} = K_P \cdot e + K_D \cdot \Delta e + K_I \cdot \int_0^t e \cdot dt$$

By replacing the integral of error  $\int_0^t e \cdot dt$  term with the sum of error term  $\sum e$ , the control law of the PID controller  $u_{PID}$  in discrete time will be:

$$u_{PID} = K_P \cdot e + K_D \cdot \Delta e + K_I \cdot \sum e$$

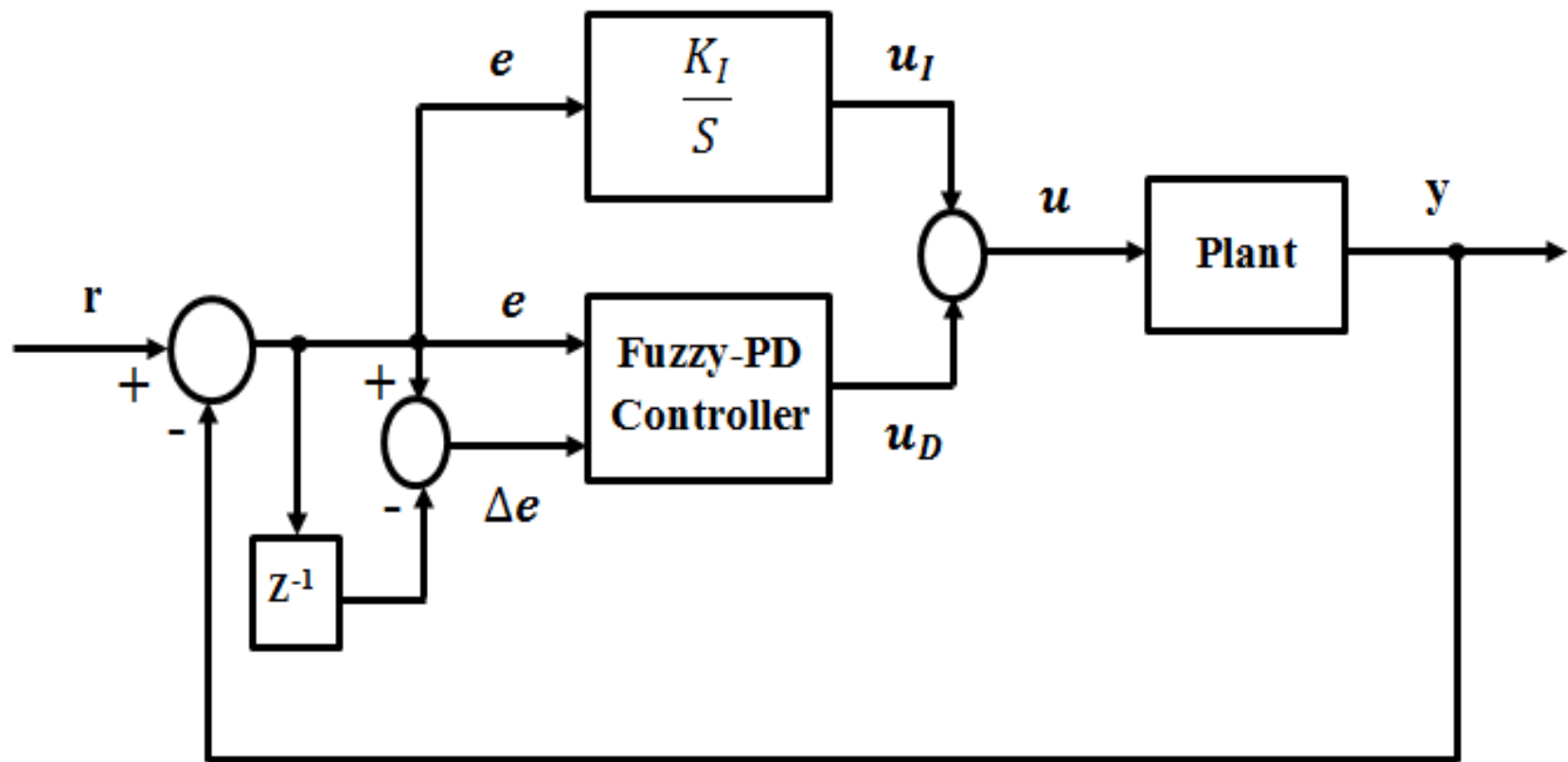
- Thus, the fuzzy PID controller can be designed by considering three inputs to the controller: error  $e$ , change of error  $\Delta e$  and sum of error term  $\sum e$  to produce the control action  $u_{PID}$ .



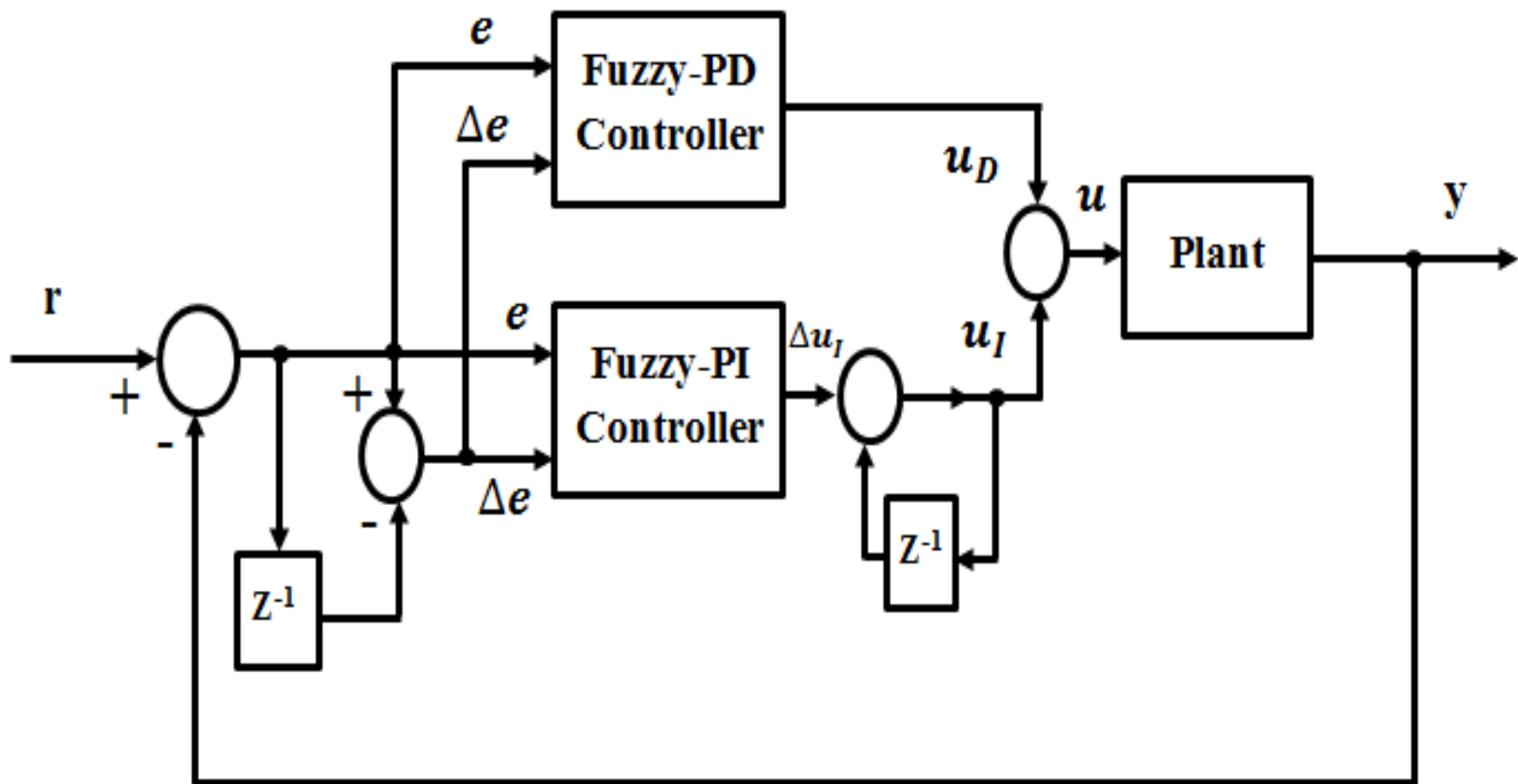
**A closed loop system with fuzzy-PID controller**

# Fuzzy-PID Controller

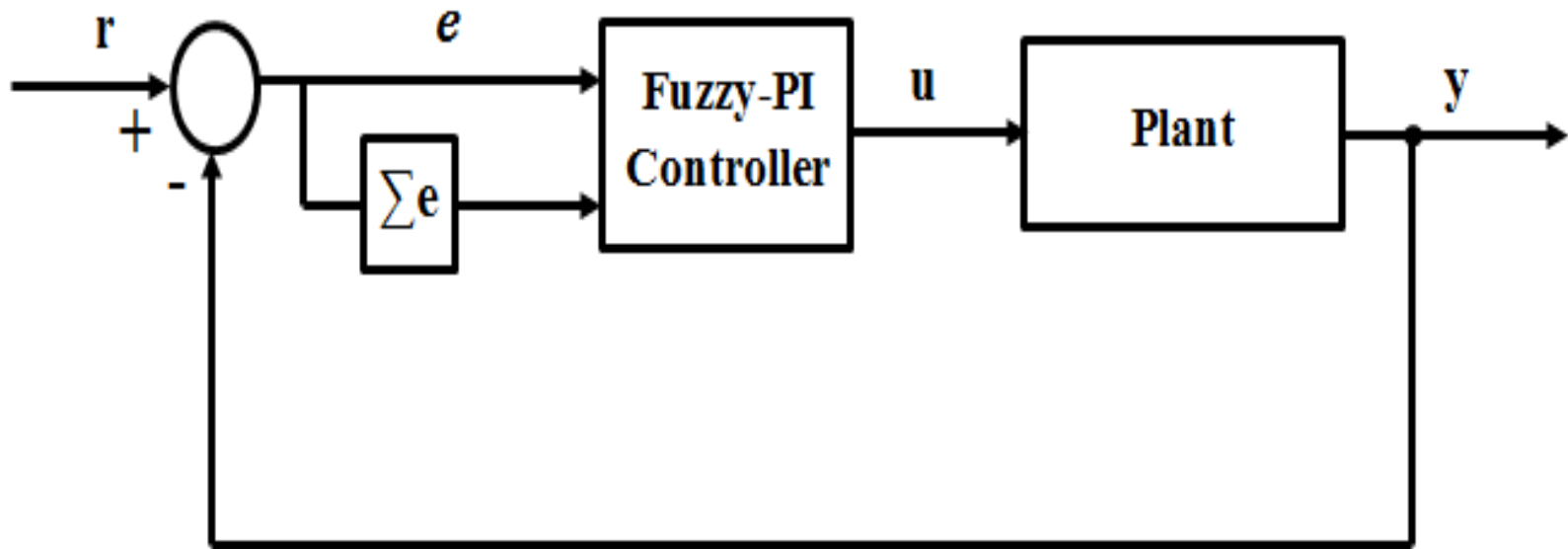
- The pervious design of fuzzy-PID controller is not suitable for practical applications (where a fast response is desired) because of its long reasoning time (based on 3 inputs which results in huge no. of rules).
- There are other various methods used to design fuzzy–PID controller which overcome the problem of long reasoning time for the pervious design, the two most common methods are:
  - 1) Combination of fuzzy-PD controller with conventional integral controller.
  - 2) Combination of fuzzy-PD controller with fuzzy-PI controller.
- In the conventional integral controller, the integral gain  $k_I$  is to be determined by trial and error.



**A closed loop system with fuzzy-PID controller**

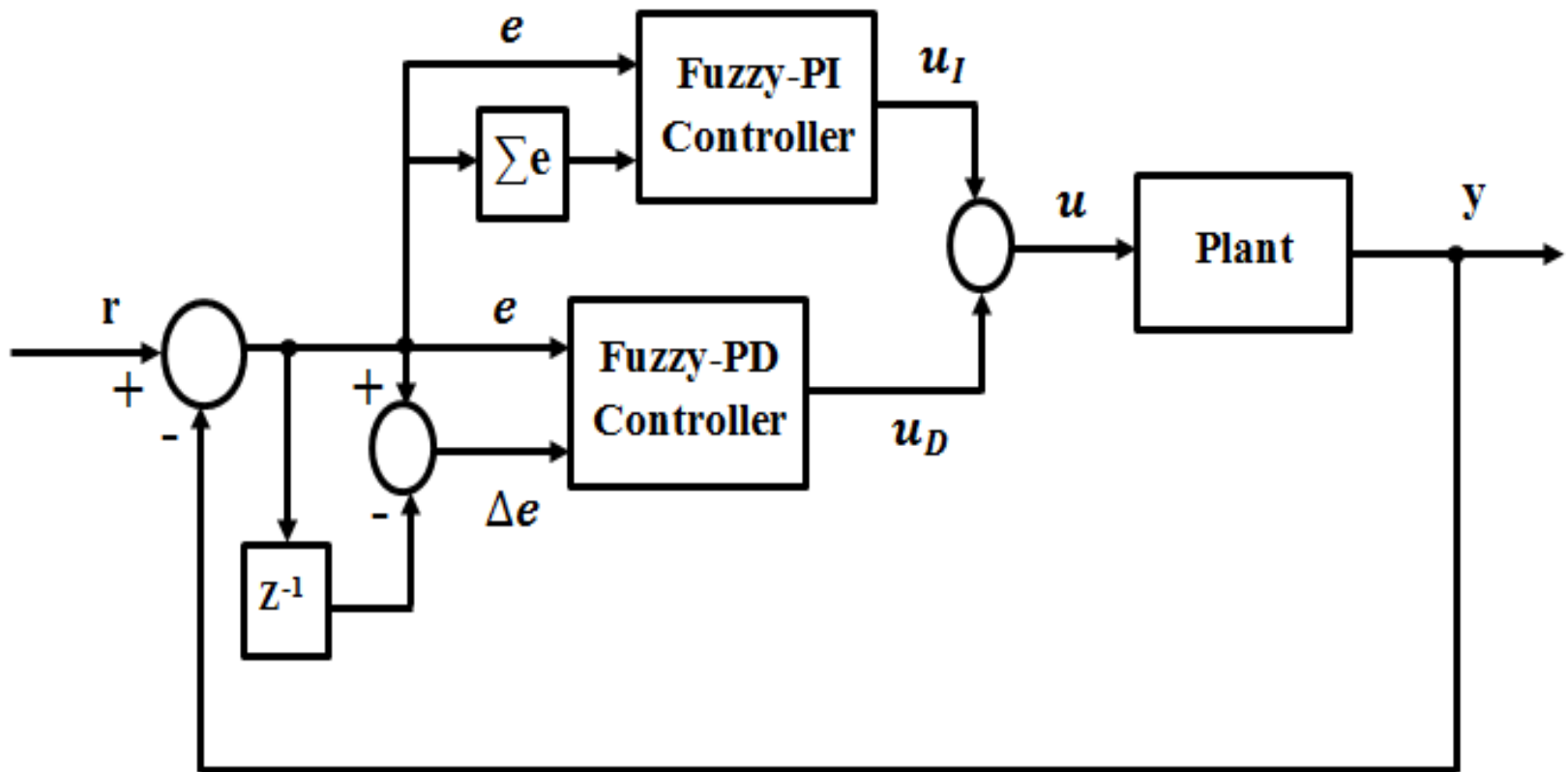


**A closed loop system with fuzzy-PID controller**



**A closed loop system with fuzzy-PID controller**

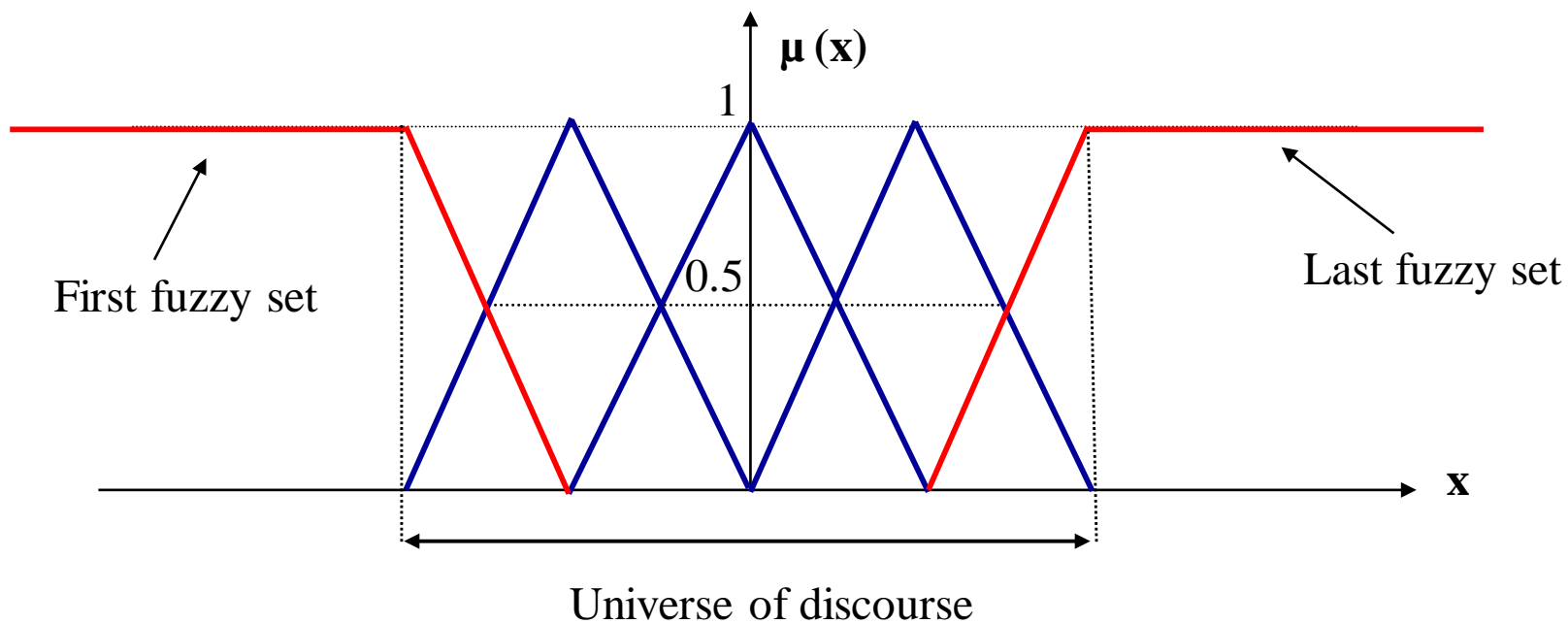
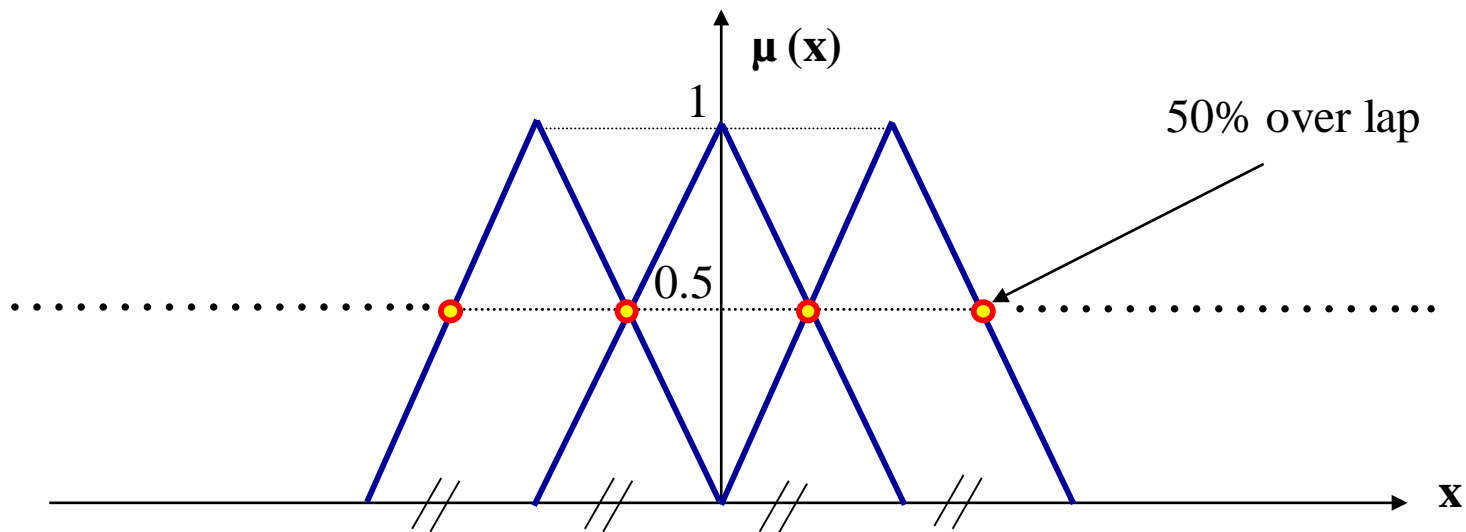




**A closed loop system with fuzzy-PID controller**

# Choosing Shapes of Fuzzy Sets Inputs and outputs for A Fuzzy Controller

- We consider the following notes to choose an acceptable fuzzy sets (as a required step) for designing fuzzy controllers (as a beginning):
  - 1) Use normal fuzzy sets.
  - 2) Use a symmetrical triangular fuzzy sets with 50% overlap.
  - 3) It is prefer to choose odd number of fuzzy sets (3, 5, 7, .....).
  - 4) To ensure that the universe of discourse covers all possible values of inputs for the fuzzy controller, the first and last fuzzy sets for inputs preferred to be as in the following figure:



- 5) The first and last fuzzy sets for output preferred to be as in the following figure:

